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Electroluminescence study of green Be-contained II–VI lasers

V. I. Kopchatov, N. Yu. Gordeev, N. D. Il'inskaja, S. V. Ivanov, P. S. Kop'ev, H.-J. Lugauer†, G. Reuscher†, A. Waag† and G. Landwehr†
Ioffe Physico-Technical Institute, St Petersburg, Russia
† Physikalisches Institut der Universität Würzburg, Am Hubland, D-97074 Würzburg, Germany

Introduction

The interest to study of II–IV laser diodes (LD) emitting in a visible spectral range is mainly caused by a possibility of their application for record high-density compact disks and for creation full-color projection TV (see, e.g., references in [1]). The recent utilization of the novel design conception of the both active region and the structure geometry led to increasing the lifetime of II–IV lasers. It is mainly owing to (a) spatial separation of the radiative recombination and defect-containing regions and (b) the prevention outside penetration and development of extended and point defect [2]. However, the basic emission parameters (threshold current density, quantum efficiency etc.) also defining the commercial application are on the outside of deep investigations.

In this paper we study the main components of the threshold current of room temperature injection lasers based on BeMgZnSe/ZnCdSe low-dimensional heterostructure and explain the characteristic lasing features observed.

1. Experimental

The laser BeMgZnSe/ZnCdSe structure investigated was grown by molecular beam epitaxy (MBE) pseudomorphically to a GaAs(001) substrate at growth temperature of 270–280°C. The MBE growth and composition control of Be-chalcogenides based heterostructures have been published elsewhere [3]. The active region of the laser diode structure contains a (10 Å-$Be_{0.05}Zn_{0.95}Se$/15 Å-ZnSe)$_{82}$ superlattice (SL) waveguide lattice-matched to GaAs as a whole, centered with a 2.6 ML-CdSe/10 nm-ZnSe nanostructure. Details of structural and optical characteristics of the active region have been given elsewhere [2]. The structure also involves 1 μm-thick wider bandgap n- and p-$Be_{0.05}Mg_{0.06}Zn_{0.91}Se$ cladding layers, doped with iodine and nitrogen, respectively, as well as a top ZnSe/BeTe:N modulation doped graded short-period SL capped with a highly p-doped BeTe:N/ZnTe:N contact structure. The 10 nm-BeTelayer was grown to produce low-resistively ohmic contact.

Broad-area lasers with 20 μm-wide stripes were fabricated by standard techniques. Laser characteristics were studied under pulsed excitation (1 μs pulse duration, 1 kHz repetition frequency) at room temperature.

2. Results and discussion

The lifetime of the samples studied was large enough to measure basic electroluminescence (EL) characteristics. We attribute the significant lifetime increasing to using:
(a) fractional monolayer (FM) CdSe/ZnSe active region grown in a special manner which allows to separate spatially defects and radiative recombination area;
(b) the Be chalcogenides, which possess the highest energy of defect-formation among II–VI compounds.

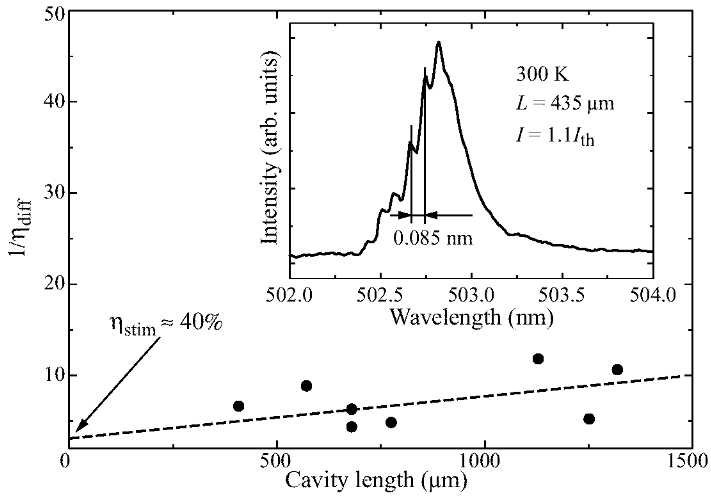

Fig. 1. The dependence of the differential quantum efficiency of stimulated emission on laser cavity length. EL spectrum of experimental sample is shown in the insert.

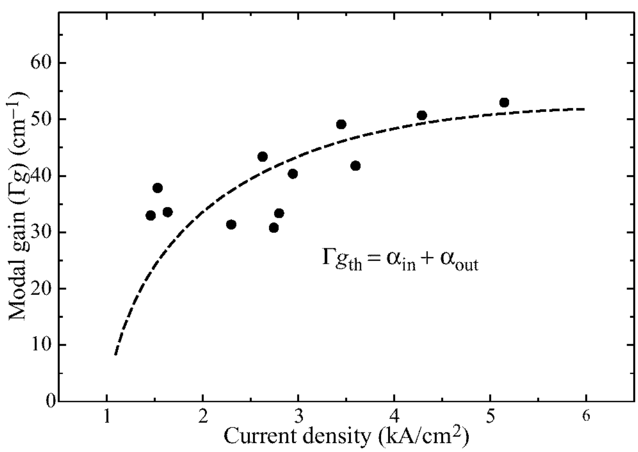

Fig. 2. The dependence of the modal gain versus threshold current density.

The dependence of the inverse differential quantum efficiency of stimulated emission versus laser cavity length (Fig. 1) demonstrates rather high value (40%) of the internal quantum efficiency of stimulated emission in the Be-contained laser structure. However, still the greater part (60%) of emitted photons is a result of a spontaneous radiation process. In our opinion this value could be significantly reduced (in favor for stimulated emission) by increasing the electronic localization.

Threshold current density dependence of the modal gain (Γg) is shown in Fig. 2. It is seen that, in spite of the rather weak rise of Γg with increasing the driving current, the gain is saturated at high values of the current density (3–4 kA/cm^2). This, so called gain saturation effect, is typical for the laser structures with an active region based on a single low-dimensional layer. The transmission electron microscopy (TEM) measurements [2] of the structure investigated showed the fractional monolayer origin of the active region which consists of the *in situ* grown CdSe-based self-organized islands. The surface density of

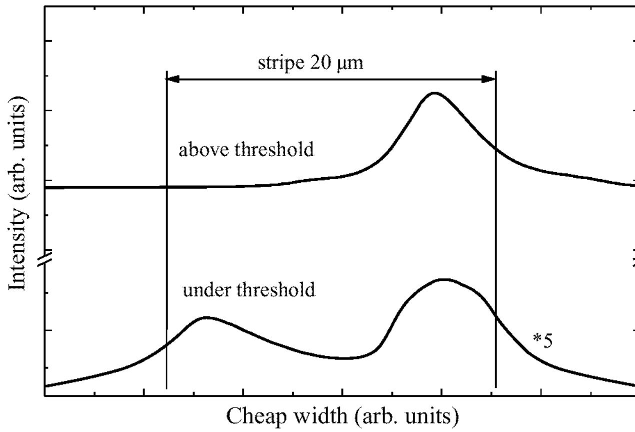

Fig. 3. Near field patterns under different pumping current for an experimental devise.

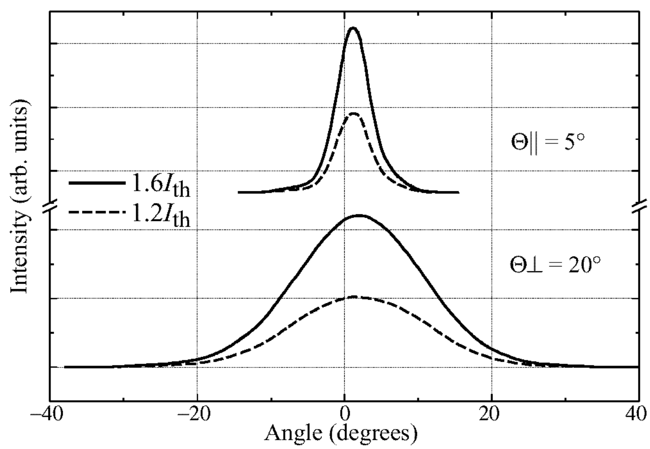

Fig. 4. Far field patterns in transverse directions at various pumping current.

islands evaluated was about 2×10^{10}–10^{11} cm^{-2} for large and small islands, respectively. Probably, the fractional configuration of the active region increases the current density, when gain saturation takes place. As follows from Fig. 2, the maximal value of the modal gain is limited by the value of $\approx$50 cm^{-1}. We suppose that it is mainly caused by not completely optimized waveguide parameters. In addition, the optimization of p-n-junction location will allow to improve the efficiency of carrier injection and to enhance the gain in the structure.

Rather high value of the threshold current and specific behavior of the gain in the structure lead to existence of the characteristic features of lasing. A change of a near field pattern with increasing the pumping current is demonstrated in Fig. 3. It is seen that at low pumping current (under threshold) two peaks with almost equal intensity appear. It should be noted that the light spot clearly distinguished at the laser mirror are located just under the stripe bounds. Above threshold the near field pattern is strongly asymmetrical because the lasing takes place only in one light spot mentioned above. At the same time a far field pattern (Fig. 4) remains uniform with increasing the current and is characterized by only one maximum in both transverse directions, resulting in the single mode operation in wide interval of the pumping current. Such behavior may be caused by anti-guiding effect, which was early observed and investigated for III–V lasers (see, e.g., [4]). It is known that an increase of injection carrier concentration leads to reduce a refractive index. In case of relatively low gain and current spreading in transverse direction gain-guiding could be suppressed. As a result the light is forced out to the bounds of the pumping area.

Analysis of electroluminescence spectra confirms the existence of the anti-guiding effect. Lasing spectra of injection laser with the cavity length $L = 435\,\mu$m is shown in the insert of Fig. 1. The indistinct pattern of Fabry–Perot modes may be attributed to the heating of the active region and neighboring layers. Using the known formula connecting the values of cavity length, wavelength, refractive index (for this compound) and dispersion relation of the refractive index allows us to calculate the "expected" mode spacing as 0.074 nm. At the same time, from the experiment Fabry–Perot mode spacing was determined as 0.085 nm. Larger mode spacing means that total refractive index of the waveguide is lower than expected one and this reduction may be caused by injected carriers.

3. Conclusions

The detail EL study of the BeMgZnSe/ZnCdSe injection laser heterostructure has been performed. It has been revealed that the enhanced device lifetime allowed one to investigate the wide spectrum of electroluminescence parameters of the RT green laser. The surface density of CdSe-based islands is shown to be sufficient for creation of the effective green laser emitters. Single mode operation of injection lasers has been demonstrated in the wide pumping current range. Anti-guiding effect has been discussed and should be taken into account in creating the lasers based on II–VI heterostructures.

Acknowledgements

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